Wave Breaking and Dissipation in the Nearshore

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LONG-TERM GOALS

The long range goal is a predictive understanding of the spatial and temporal variability of wave breaking in the nearshore, and the impact of wave breaking on the forcing of mean and oscillatory flows, sediment transport, and changes in large scale nearshore morphology.

SCIENTIFIC OBJECTIVES

(1) Improved modeling of wave transformation, wave breaking distributions, and surface wave stress on barred bathymetry

(2) Improved understanding of infragravity waves, their forcing by modulations in wave breaking patterns, their cross-shore variation across the surf zone

(3) Pilot measurements of wave breaking on the inner shelf

APPROACH

The difficult problem of understanding wave dissipation in the nearshore is approached through field observations made across a variety of beach profiles and under a wide range of wave conditions. Data are obtained remotely from video recordings of the surf zone and inner continental shelf, and image processing techniques are used to detect and quantify wave breaking over spatial and temporal scales ranging 10-1000 meters and 10-10000 seconds. The observed spatial distributions of ensemble-averaged wave breaking distributions are used to improve numerical dissipation estimates, and subsequently applied to parametric models of incident wave energy transformation and mean current forcing within the surf zone. The forcing of low-frequency oscillatory motion through spatial and temporal variations of the point at which a wave breaks is being approached through a combination of theory and observation. The relationship of wave breaking to sediment transport is being pursued through co-located video observations and collaborative in situ measurements of sediment concentration, turbulence, and void fraction (air concentration).

WORK COMPLETED

Recently, continuous observations over a 3 month period of wave breaking were obtained as part of the SandyDuck field experiment held in the summer and fall of 1997. The spatial and temporal variations in the breaking wave field in and near the surf zone were quantified with an array of shore mounted daylight and intensified (night-time) video cameras mounted on towers of varying height. The relationship of breaking variability to the distribution of longshore currents, set-up, suspended sediment concentration, and ripple fields in relation to the offshore sand bars in the surf zone and the whitecapping on the inner shelf, is being examined collaboratively in detail with SandyDuck participants.

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RESULTS

Observations of wave breaking at a number of alongshore transects spanning several hundred meters alongshore and extending from the shoreline to beyond the width of the surf zone, were made continuously for over 2 months during the 1997 SandyDuck experiment utilizing both daytime and intensified night-time video cameras.

Empirical algorithms have been developed to identify the location of individual breakers in digitized timestack imagery (Holman, *et al.*, 1993). The precision of identifying the maximum intensity and leading edge of the breakers is estimated to be generally 1 pixel, or within the resolution of the image (0.5-1.0 m). The accuracy in detecting breakers from other non breaking features is estimated at within 1-2% of the total identified breaking waves for most days, but can be as much as 5-10% for stormy periods when the contrast at the sea surface is greatly reduced.

The identified location of individual breakers in the timestacks is used to compare with other in situ or remote sensing instrumentation within the camera's ground field of view. This data is being used to examine occurrences of breaking events with sediment concentration time series at the same spatial location and time.

The number of breaking waves at a given cross-shore location are summed over various time intervals, normalized by the total number of waves, and then used to calibrate wave transformation models used in modeling mean flow (Reniers, *et al.*, submitted; Garcez Faria, *et al.*, 1998; Garcez Faria, *et al.*, submitted). The variation of the breaking patterns during SandyDuck was strongly tidally modulated (Figure 1), with advection distances of breaking waves through the trough of the bar increasing with the tide, a result expected from the wave breaking transformation model including wave rollers (Lippmann and Thornton, submitted) and previous observations of longshore currents (Thornton and Kim, 1993). Surprisingly we find strong 10-30% variations in the average breaking patterns with time scales on the order of 30-40 minutes. The origin of these modulations and their effect on the forcing of very long period oscillatory motions and sediment suspension events is not yet known, and is presently being investigated.

Variations in breaking patterns at longer (order days to weeks) time scales are examined by using continuous observations over the 2 month long deployment. The variability in breaking patterns is determined by combinations of changes in incident wave energy, manifested in slowly varying fluctuations in surf zone width, and changes in the water depth determined by the amplitude and location of sand bars and strong modulations at tidal frequencies.

A cross-shore array of 9 co-located pressure sensors and bi-directional current meters from the 1990 Delilah experiment (P. I. Thornton), extending from the shoreline to approximately 4.5 m depth, were used to estimate the relative contributions of gravity waves and instabilities of the longshore current (shear waves) to motions in the infragravity band (Lippmann, *et al.*, 1998). Outside the surf zone where the shear of the longshore current is relatively weak, the observed total infragravity velocity to pressure variance ratios (normalized by g/h) are approximately equal to 1, consistent with an infragravity spectrum dominated by gravity (edge and/or leaky) waves. Inside the surf zone where longshore currents are strongly sheared, these normalized ratios are much larger, up to 8 on some occasions, indicating that shear waves contribute as much as 75% of the velocity variance in the infragravity band. Energetic shear waves are confined to the (often) narrow region of strong shear on the seaward side of the longshore current maximum (Figure 2), and their cross-shore structure appears to be insensitive to the beach profile, consistent with the theoretical predictions by Bowen and Holman (1989). In addition, during low-energy incident wave conditions, infragravity pressure variance decreases with increasing depth qualitatively consistent with the theoretically predicted unshoaling and trapping of gravity waves. However, during high- energy incident wave conditions, the observed infragravity pressure variances are nearly uniform across the surf zone,

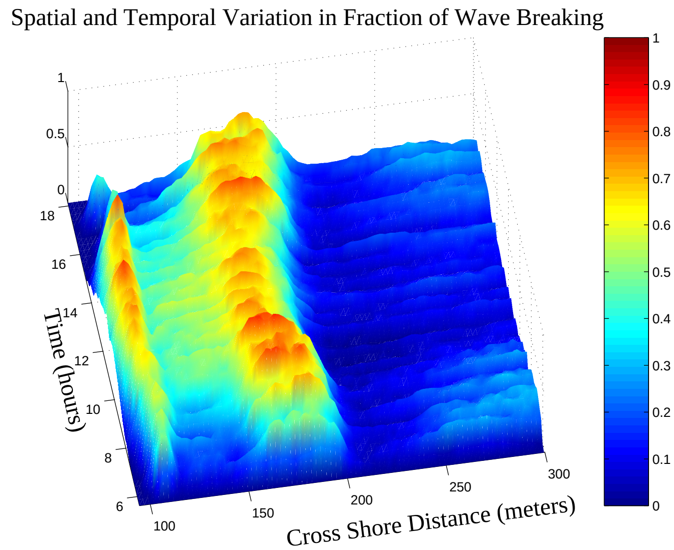

Figure 1: The spatial fraction of breaking waves determined over successive 5 minute intervals from timestacks spanning a 12 hour period on 21 October 1997 during the SandyDuck experiment. Both the height of the surface plot and the color scaling, shown in the color bar on the right, are proportional to the breaking fraction. Observations shown in the Figure extend from the shoreline, past the inner sand bar, and out to about the second bar crest. The breaking fraction of the wave field approaches unity over the shallows of the bar, and again near the shoreline. The fraction of breakers decreases in the bar troughs, with substantially more breaking occurring landward of the inner bar at higher stands of the tides. Also clearly observed are 15-30 % fluctuations in the breaking patterns with time scales on the order of 30-40 minutes, much longer than typical wave groups with periods of O(1-3 minutes).

suggesting strong scattering effects in a wide surf zone (Lippmann, *et al.*, 1998).

Intriguingly, recent analysis of only the cross-shore pressure array from Delilah, indicate that infragravity surface gravity wave energy is locally maximum over the shallows of the sand bar (perhaps indicating the presence of low-frequency bar-trapped edge waves similar to observations of Bryan, *et al.*, 1998), and appears to be more strongly amplified when the bar morphology becomes three-dimensional (Figure 3). The coincidence of increased turbulence produced by high numbers of wave breaking, suggests that three-dimensional bar evolution may be linked to the combined effects of breaking induced sediment mobilization and suspension and subsequent transport by energetic infragravity waves over the bar.

IMPACT/APPLICATIONS

Wave breaking is the principal driving force for currents, mean water level changes, and low frequency oscillatory motions within the surf zone, and is also believed to be of order one importance in sediment transport and large scale sand bar evolution. However, simple parameterizations needed to describe the complicated dissipative mechanisms have not generally been guided by observation. Only with recent advances in remote (video, acoustic, microwave, infrared, radar), and in situ (void fraction) instrumentation, has quantifying the breaking process been possible, and improvements in the sampling and modeling of wave breaking should lead to

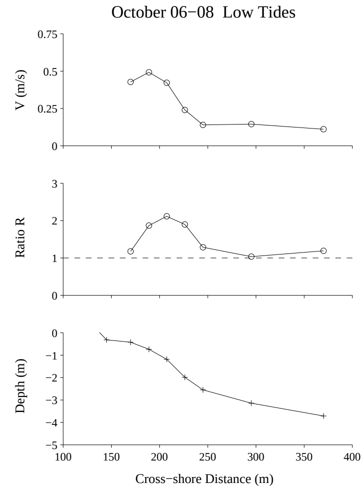

Figure 2: The observed ratio *R* (center panel), of the measured total infragravity velocity to pressure variance ratio normalized by the theoretical prediction for gravity waves (g/h), over all low-tide observations from 6-8 October during the 1990 Delilah experiment. A purely gravity wave field would be given by values of $R = 1$, whereas values $R > 1$ indicate the presence of shear waves ($R = 2$ indicates shear waves contribute 50% of the velocity variance in the infragravity band). Nearly all of the shear wave energy was confined to a region of strong seaward shear in the mean longshore current profile (upper panel), and did not vary in accordance with the bathymetric profile (lower panel).

much improved understanding the kinematics of wave breaking and its dynamical implications.

TRANSITIONS

Our video analysis techniques developed as part of this research have been used to develop a quantitative aerial video system used in USGS-sponsored regional studies of the North Carolina and southern Californian coastlines (PI's Lippmann, Haines, and Sallenger).

RELATED PROJECTS

Video data analysis of the 1990 Delilah, 1994 Duck94, and 1996 MBBE experiments has been examined in collaboration with other ONR funded scientists. We have also developed an aerial video system for measuring the very-large scale nearshore morphology from time exposure video images spanning about 100 km of coastline (Sponsored by the U. S. Geological Survey, Co-PI's Haines and Sallenger). The system is an expansion of the ONR and USGS sponsored projects to develop video techniques for measuring nearshore morphology and bathymetry.

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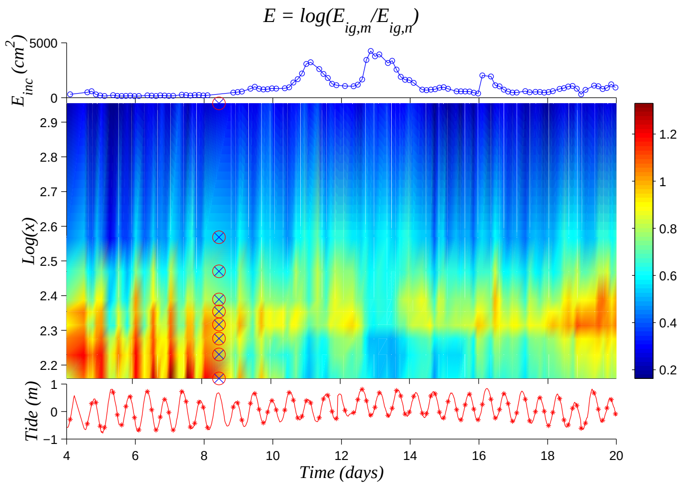

Figure 3: Log normal ratio, E, of surface gravity wave energy, integrated over the infragravity portion of the spectrum, obtained at depths spanning the width of the surf zone (subscript m) to that in 13 m water depth (subscript n) during 16 days of the 1990 Delilah experiment. The color shading is proportional to E, and cross-shore distance is log normalized to emphasize the region close to shore, and the location of a well-developed sand bar at approximately 80-90m offshore ($log(x) \approx 2.3$) that formed on 9 October. The offshore wave energy is shown in the upper panel for reference to the storm events, and the tide elevation is shown in the lower panel. The observed seaward decay in infragravity energy is strongly tidally modulated, but shows very little association with offshore wave height. Infragravity energy is also nearly uniform across the surf zone except for a local maximum over the shallows of the bar, and becomes further amplified as the morphology becomes three- dimensional toward the end of the experiment (18-20 October). The cross-shore location of instruments is shown on the plot by the crossed circles (arbitrary shown on 8 October).

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